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Achieving Adaptive Augmented Reality through Ontological Context-Awareness applied to AAL Scenarios

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Abstract: This paper presents a proposal for supporting daily user needs by simple interactions with the environment through an augmented-reality perspective that applies proactive adaptation through knowledge representation using ontologies. The proposed architecture (i-ARA) uses principles of the Semantic Web that endow context-awareness and user personalization. In addition, these types of services allow the supervision and management of what is happening in the environment and, consequently, improve the information offered to users. The architecture has been used to implement applications using iPhone technology and has been applied to illustrative scenarios, including Ambient Assisted Living.

Keywords: Augmented Reality, Mobile Computing, Context-Awareness, Ambient Assisted Living, Semantic Web
Categories: I.2.4, H.5.2, M.4

1 Introduction

People need particular information everywhere and at all times to perform their daily activities. This information is provided by a variety of devices, of which mobile devices are currently the most common. Typically, mobile devices offer information that is static or based on simple parameters such as location or explicit user requests, and they typically use traditional user interfaces. However, mobile devices can enhance interactions between users and their surroundings by a combination of real world and computer generated data that is called mobile augmented reality.

Bearing in mind these premises, we envision the development of augmented reality systems following the metaphor <how to>; that is, the environment establishes guidelines—i.e., information organized as a flow diagram—for the performance of a task by positioning significant elements whenever the user interacts with an augmented object in the environment. We consider an augmented object to be any thing, person or area in the environment that has associated information and offers a mechanism to interact with and share the linked information. Having acquired the information from an augmented element, the user receives guidelines for the desired activity. This scenario leads to the main problem: there is not a unique relationship between an augmented element and the needed information. To disambiguate this relationship, we propose to endow context-awareness using the principles and languages of the Semantic Web. The definition of a formal context model of users and their surroundings can determine what information they require by applying the semantic axioms of the language associated with the context model and defining behaviour rules that represent how the user's world works.

The challenge for this paper is to define mechanisms for the management of contextual information, reasoning techniques and adaptable user interfaces to support augmented reality services that provide functionality to make decisions about what available information should be offered and how.

This paper is organized into seven sections. After this introduction, Section 2 shows how to apply context-awareness using the languages of the Semantic Web. Section 3 presents a general architecture for generating augmented-reality-based mobile applications, which link information to relevant elements in the environment, and techniques to formalize the representation of the user world and infer what information users want to obtain. The architecture also includes algorithms for positioning the relevant elements in the user interface at run-time. Section 4 describes some prototypes and illustrates the reasoning and information retrieval mechanisms. We describe the evaluation of our system in section 5 and introduce related work in Section 6. Finally, Section 7 presents the paper's conclusions and contributions.

2 Context-awareness through semantic web principles

Personalized and adaptive behaviour, an important and desirable characteristic for mobile computer systems, has been studied for many years. These types of systems require models that describe the real world and, in a human-like manner, abstract from the complexity of the real word to understand it, at least in part. Only by understanding the world around us will applications be capable of making daily activities easier. Context-aware applications offer opportunities for smarter services in intelligent environments and, more specifically, for offering personalized information to users depending on their current needs.

In this paper, we describe the ideal scenario in which users receive exactly the information they need, at any moment, throughout their activities. This ideal is far from reality, but this work offers a contribution to that end; we present an infrastructure supporting information adaptability to users by describing the context situation with Semantic Web languages and offering needed information through an augmented-reality perspective

2.1 Introduction to Semantic Web

Advances in the Semantic Web enable people and machines to share information, describing the semantics of concepts and services on the Web (and also outside the Web). Focusing our approach on the Semantic Web helps us to reduce the human cognitive effort required to access information and facilitates a semantic description that enables machine analysis and interpretation of the particular user situation. The adaptation of Semantic Web principles to Pervasive Environments offers important benefits, mainly in context modeling. The representation of context in particular, by means of ontologies, will become a substantial part of the design and maintenance of context-aware systems. Expressing context in Semantic Web Languages can provide a rich and unambiguous definition of relevant concepts in the domain environment.

The architecture of the Semantic Web is built upon a set of languages and technologies. The syntax is provided by XML. The mechanism to represent information about resources is known as Resource Description Framework (RDF) [W3C, 2010], and the taxonomical organization is enabled using the RDF Schema. Web Ontology Language (OWL) [W3C, 2009] extends the RDF Schema by including more expressive constructors to describe the semantics of the elements. Finally, SPARQL [W3C, 2008] is a query language to retrieve information from web data sources.

2.2 Ontological Context Model

Based on these premises, the information associated with augmented elements has been described using the OWL language and is part of a general context-model. The proposed model defines four taxonomical elements (see Figure 1):

- User ontology: This element describes the user profile, their situation, and their social relationships. The user model has been designed to represent the characteristics of the user, what the user wants to do, and what the user is doing. This model leans on the Friend of a Friend (FOAF) specification [Brickley, 2010]
- Device ontology: This element is the formal description of the relevant devices and their characteristics, associations, and dependencies. Mobile-based applications must support the spontaneous inclusion and evolution of new devices, acquiring their characteristics and upgrading the application behavior. This ontology is compatible with well-known device specifications such as the UAProf [Mobile Multimedia, 2012] specification, which is concerned with capturing information for wireless devices, and the FIPA Device Ontology [FIPA, 2000], which aims to be general but offers low-expressiveness in peripheral device description.
- Physical environment ontology: This element defines the spatial distribution and models objects and their physical relationships. The ontology has been designed based on a taxonomical organization and follows a premise of generality to be applicable to multiple domains. Consequently, the level of detail is low, and it is necessary to adapt the model to the peculiarities of each environment.
- Service ontology: This element is an ontology that specifies the context model to the particular applications and services to be offered to users.

Specifically, the service ontology for this proposal includes data needed to transform the physical position of elements into elements of the augmented-reality user interface. These data are instances of the following classes:

- oName: representative name of the element.
- oDistance: distance between object and user.
- acclrmtr: height of element in reference to the user.
- cmpass: degrees of the element around the user.
- AugmentedObject: OWL URI of this element.
- Multimedia: related multimedia content.

Figure 1 shows an overview of the context model [Hervás, 2010], including the main elements of the model, and the service ontology adaptation to augmented-reality-based services.

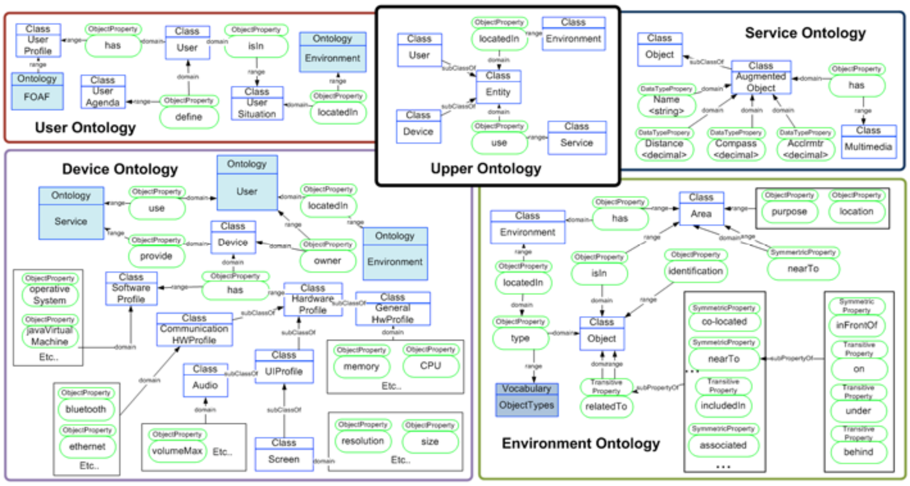


Figure 1: Context Model Ontology Overview

2.3 Personalization through reasoning techniques

Languages based on the description logics foundations (e.g., OWL-DL) allow us to apply the language semantics in order to obtain new information from previous information.

Additionally, it is possible to combine description logics with rule-based systems to improve their reasoning capabilities. In general, reasoning techniques enable the definition of consistency rules, reducing the ambiguity in the context information, and thus maintaining and improving the information quality. Apart from these benefits, reasoning techniques allow us to determine what information should be shown to the user, not only based on the explicit data about user situation or user preferences but also information proactively inferred through reasoning techniques.

OWL defines an inherent semantics that enhances the inference capabilities of our system at the level of classes as well as individuals (i. e. instances or specific elements that belong to a class). The semantics is defined through formal class axioms, descriptions (e.g., UnionOf, intersectionOf, complementOf, etc.), restrictions (e.g., Cardinality), and property axioms (e.g., InverseOf, subproperty, etc.).

Moreover, the context-aware augmented-reality-based applications developed under our proposal define their dynamic behaviour using SWRL [Horrocks, 2004]. This language extends the semantics of the OWL axioms and follows the antecedent-consequent schema. Both the antecedent and consequent may be formed by a set of atoms that can be class descriptions, data ranges, and model properties. Finally, SWRL defines several built-in operators (comparisons, math, Booleans, string, and time operations).

The next sections elaborate these concepts and include illustrative and practical examples.

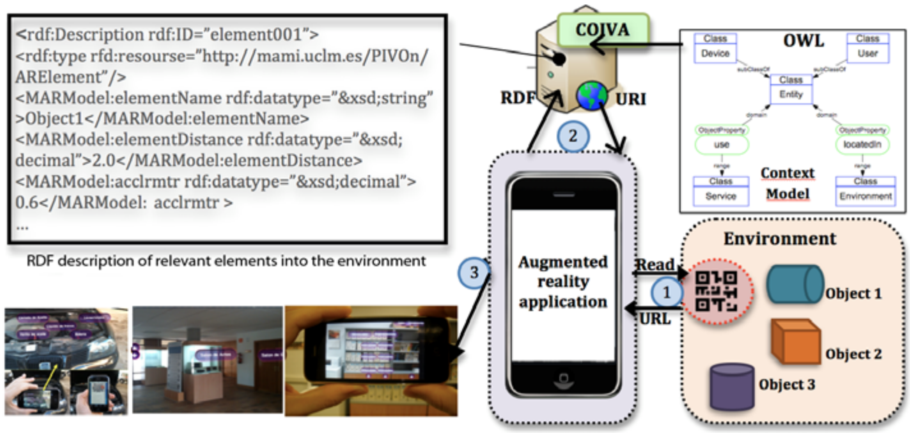


Figure 2: i-ARA architecture overview

3 Intelligent Augmented Reality Architecture (i-ARA)

This section is focused on describing the generic architecture that we have designed to generate context-aware, augmented reality mobile applications in a general, reusable and applicable way. This architecture permits the transformation of situation information about real-world objects into an understandable language for mobile devices and also defines the correlation between device movement and automatic adaptation of elements in the user interface. This model is independent of any specific mobile device, as long as accelerometer and digital compass data are provided. For this formal description, the model includes a language based on RDF to describe situation information about the relevant real-world objects.

3.1 Architecture Overview

The i-ARA architecture (Figure 2) implements the principles defined by MARM and includes mechanisms to provide context-awareness. RDF-based information is transformed into OWL instances. Additionally, the architecture maintains a representation of user situation and surroundings (context model). Based on this information and the knowledge base for each scenario, it is possible to determine which elements to display depending on user needs.

Figure 2 shows the whole process where information obtained from a server is represented on the screen of the device. First, the mobile device has to read the augmented object URI reference. This reference corresponds to information stored on the server to be downloaded (1). In the second step, the mobile device requests the information from the server, which responds with the file containing the RDF description (2) of the parameters that describe the location of all relevant elements. Finally, the user receives generated interfaces to relevant objects in the augmented reality view (3) based on the user's situation and the defined SWRL rules. Concretely, the COIVA architecture [Hervas, 2011a] manages the context information. This architecture, in addition to providing a specialization mechanism, supports the dynamic maintenance of context information. The reasoning engine hastens the start-up process, enabling the automatic generation of ontological individuals. Moreover, context-aware architectures tend to generate excessive contextual information at run-time. The reasoning engine can support the definition of updating or deleting policies, keeping the context model accurate and manageable.

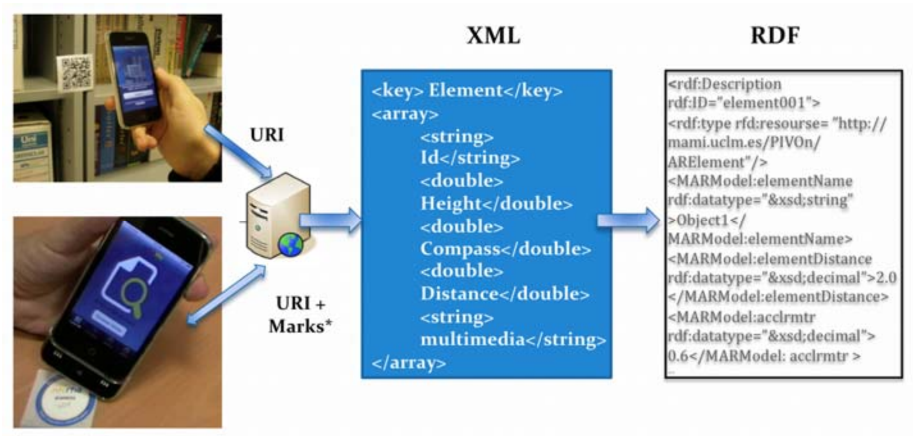


Figure 3: General XML and RDF representation of information associated with an augmented element. Acquisition through NFC and QR code.

3.2 Interaction techniques and data acquisition

The proposed model tries to be general and technology independent; however, it is necessary to know the area or object of user interaction. This entails three particular requirements:

- Mechanisms for linking information to relevant elements in the environment, at least a URI reference.
- Enabling interaction between users and augmented elements. At a minimum, this interaction has to allow reading of the URI reference. This interaction should also be natural and easy for users following ambient intelligence principles. It is also desirable, but not indispensable, to enable writing capabilities for recording information whenever a user interacts with an augmented object. In this way, we can personalize future interactions based on previous ones, similar to web browser cookies [Hervás, 2012] i.e., capturing information in the augmented object regarding how users interact with it and adapting the object's behaviour accordingly.
- Supporting communication between the mobile device and the COIVA server.

In our prototypes (Figure 3), we have tested QR codes and NFC technology, obtaining similar results and validated both technologies for applications based on i-ARA, but highlighting the writing capabilities of NFC

3.3 Architecture Overview

The information retrieved for display to users is selected on the basis of two principal criteria: A matching between user information, the interacted augmented object and explicit user-provided search terms (if he/she enters search terms) and the behavioral rules defined for the specific visualization service.

Focusing on the first criterion, we based the selection on certain individuals in the ontological context model that link the user, the augmented object and the search terms. In more detail, we obtain a quantitative measure of significance in the range of [0,1] based on these individuals; this measure is inversely proportional to the distance between each user-object, user-term, and object-term pair, that is, the number of relationships between each pair of ontological classes [Hervás, 2011b]. We select the elements with the highest score. Specifically, this mechanism exploits OWL semantic axioms, obtaining relevant information that is not explicitly included in the context model.

However, information personalization cannot be based solely on the existence of certain individuals in the context model. It is necessary to include more complex mechanisms to select the candidate contents to be offered. These are mechanisms based on SWRL rules powered by built-in constructors and XQuery operations that enable selection by the particular value of an ontological instance and applying math, Boolean, string or date operations. We show some practical examples in Section IV.

3.4 Visualization Algorithms

We have defined mechanisms to transform the object information and device sensor parameters into augmented information in the user interface at run-time. Once the parameters that define the spatial position of the relevant objects in the environment are acquired, a virtual representation is displayed on the screen based on current user point of view. Additionally, the mobile device analyzes values from sensors to refresh the elements in the X-axis using the compass values and the Y-axis using the accelerometer values as the user moves.

These algorithms (see Figure 4) are device-independent and must know the particular features of the mobile device, specifically, the screen characteristics (ScreenWidth, ScreenHeight and angleOfView) obtained from the device ontology. The algorithms determine if the object is in the camera's field of view. The object's presence in the field of view is determined by calculating the absolute value of distance (in degrees) between the object and the compass position. If the object must be shown inside the screen, the algorithm returns its position in pixels (pointX). If the object is out of the field of vision, we must decide whether to specify its adjusted position on the left side or in the right side. This problem is solved in the first section of the algorithm.

A similar procedure is used to determine the vertical position of the virtual object. The conditions are equivalent, but compass values are exchanged for accelerometer (acclmrt) values.

$$pX\begin{cases} Abs(objX - cmpass) > \left(\dfrac{kDegreesVision}{2}\right) : pX = \begin{cases} cmpass < 180 : pX = \begin{cases} (objX > cmpass)\ \&\ (objX < (cmpass + 180)) : pX = kXAxisRight \\ (objX <= cmpass)\ \|\ (objX >= (cmpass + 180)) : pX = kXAxisLeft \end{cases} \\ cmpass >= 180 : pX = \begin{cases} (objX < cmpass)\ \&\ (objX > (cmpass - 180)) : pX = kXAxisLeft \\ (objX >= cmpass)\ \|\ (objX <= (cmpass - 180)) : pX = kXAxisRight \end{cases} \end{cases} \\ Abs(objX - cmpass) <= \left(\dfrac{kDegreesVision}{2}\right) : pX = (objX - cmpass) * \left(\dfrac{kWidthPixels}{kDegreesVision}\right) + \left(\dfrac{kWidthPixels}{2}\right) \end{cases}$$

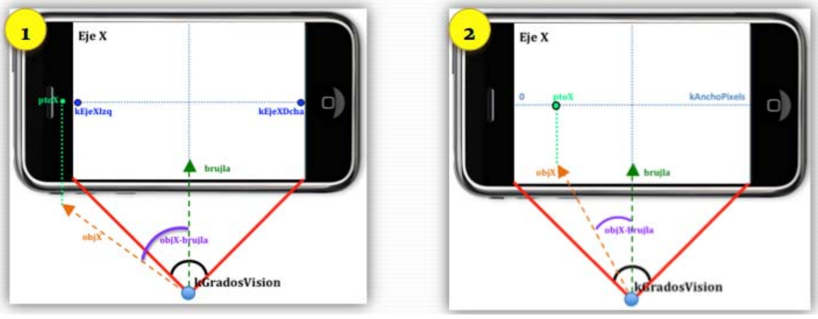


Figure 4: Algorithm to determine the vertical position of the element based on compass data at run-time.

4 Applications

This proposal follows a generic perspective and can be applied to multiple scenarios. In this section we describe some particular prototypes to illustrate the contributions of our work.

4.1 Collaborative Work Scenario

We focus on a scenario that involves groups of users that share interests and agendas, work collaboratively and have a dynamic information flow, for example, people working together in a research lab.

The first example addresses finding resources in the environment such as a printer. The user selects a particular area and obtains people or places with printers available to the user. The trivial case would be to retrieve printers owned by the user. Our context-aware approach enables more intelligent behaviours, for example, retrieving information about printers that are directly or indirectly linked to the user through OWL properties.

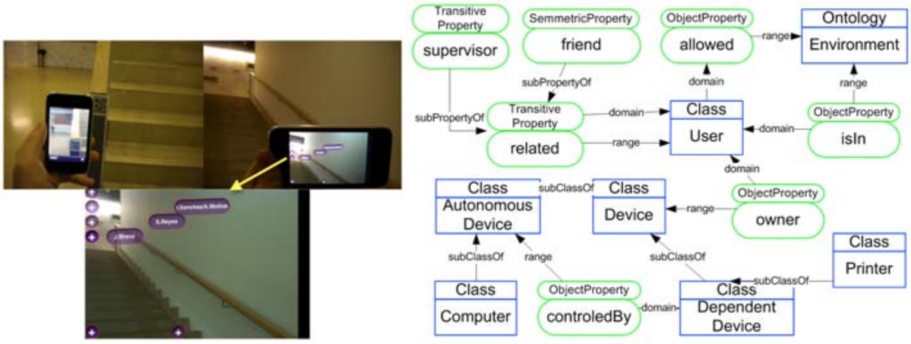


Figure 5: Classes and properties involved in the printer example.

All of this information is represented in the context model; consequently, it can be obtained following the distance criterion. Figure 5 shows this example graphically and includes the portion of the context model that is involved in this scenario. In the photograph at the bottom of figure 5, the system displays three printers to the user. Next, we are going to describe how this system chooses the information to retrieve based on the contextual information. The classes and properties of the context model are remarked in *italics*, and the instances of classes are shown in **bold**:

- Printer of J.Bravo: **J.Bravo** is a known user in our scenario and is also an instance of the User class in the context model. J.Bravo supervises the current user (*supervisor* is a subclass of the property *related* that links two *Users*). He is the *owner* of a *computer* with a *printer*, and he *is_in* his office. The fact that J.Bravo and his printer are in the office do not affect the distance criterion. However, it determines where the printer's label must be located on the screen and tells us that we can have access to the printer because J.Bravo is in his office. The distance criterion value is 0.33 because there are 3 elements between the current user and the information to show, in this case the available printer of J.Bravo. Figure 6 shows the involved classes and properties graphically.

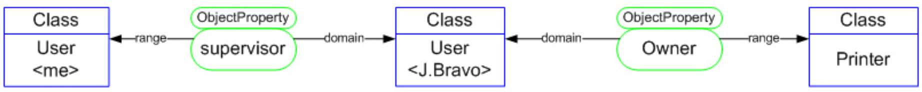


Figure 6: Classes and properties involved in obtaining J.Bravo's printer.

- Printer of S.Reyes: As Figure 7 shows, **S.Reyes** is an instance of the *User* class. He is a *friend* of **J.Bravo** (transitive and symmetry properties) who is *allowed* access to a **printer-room**, and he is located in his **office**, an instance of the Environment class. In this case the distance criterion value is 0.14.

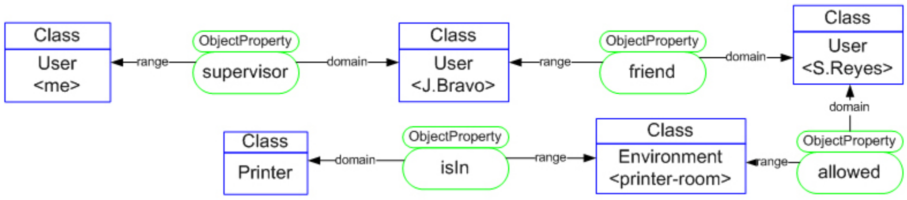


Figure 7: Classes and properties involved in obtaining S.Reyes's printer.

- Printer of A. Molina: She is an instance of the *User* class. She has a **tablet-pc** with remote access to printers. We do not know her location, but her **tablet-pc** is in the *office* of **I. Sanchez**; she may be there too. In this case, the distance criterion value is 0.2. (Figure 8)

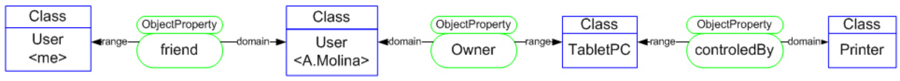


Figure 8: Classes and properties involved in obtaining A.Molina's printer.

Thus, the distance criterion between users and printer instances through model properties determines which elements must be shown. Regarding this criterion, there is no magical threshold to pass. The choice of information based on this distance depends on the particular scenario and the involved context (for example, a distance value of 0.2 could be very good or very bad, depending on the situation). In our prototype we have adopted a simple solution: we follow Miller's Law [Miller, 1956] from psychology, which states that 7±2 is the average number of objects that a person can hold in working memory. More specifically, we display on screen the nine most valuable information elements obtained from the distance criterion.

The second example is an application to retrieve relevant documents from a library or archive. The user context model helps to determine what documents should be displayed based on the user's topics of interest. In this case, the criterion based on the element's distance would retrieve all documents whose topics are also topics of interest to the user. However, it is much more efficient to define a behaviour rule that obtains the same result. In particular, this functionality has been implemented through the SWRL rule included in Figure 9.

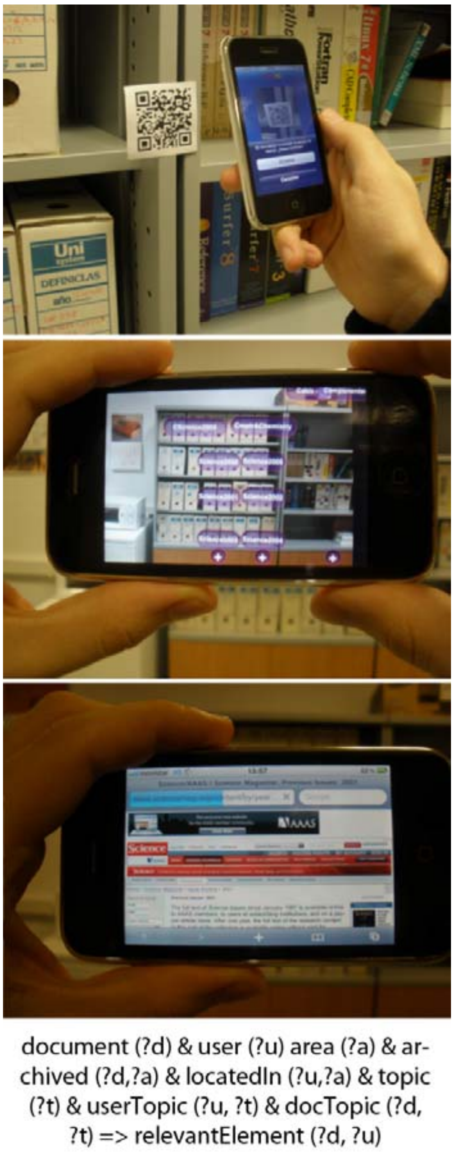


Figure 9: Information retrieval of relevant documents through a SWRL rule.

4.2 Ambient Assisted Living Scenario

Elderly people living alone at home need support for daily activities. For this reason, the Ambient Assisted Living (AAL) [EU, 2012] initiative promotes the use of technologies for helping elderly people to maintain their autonomy, increase their quality of life and facilitate their daily activities but bears in mind that usability is crucial.

Elderly people living alone may have a neurodegenerative medical condition that causes cognitive impairments or light behavior disorders. As a consequence, they can have trouble performing some daily activities. It is important to contribute to the patients' ongoing improvement or maintenance while preserving personal independence and social functioning.

As we stated previously, we follow the <how to> metaphor; that is, the environment establishes guidelines for how to perform a task whenever the user interacts with an augmented element in the user's home. We consider an augmented element to be any object or area in the environment that has some associated information and offers a mechanism to interact with and share that information.

Table 1 shows several examples, including the semantic rules applied to adapt the information shown and several illustrative pictures. The first example tries to help in the performance of daily activities such as turning on the washing machine or switching on the heat. The second example provides information about what meat to cook and shows the steps to prepare it. In this case, the system chooses between several recipes depending on current biometrical signals from the user that can be obtained from proposals such as the MoMo Framework [Bravo, 2012] and integrated into the context model. Finally, the third example infers the application behaviour through SWRL rules based on what medications the user needs at that moment. It also detects when the user needs to request medicines and updates the augmented-reality-based calendar with a physician appointment.

5 Evaluation

We evaluated the prototypes through interviews and user studies. Twenty users (twelve men, eight women) participated in the experiment over a period of four days. The experiments were incorporated into their daily activities to simulate actual situations. The amount of time that each user tested our prototypes was 15 min per day, on average. The population included ten engineering undergraduates, two Ph.D. candidates, two professors, and eight users not related to university (in particular, they were not familiar with new technologies), all between the ages of 21 and 59. In the future, we plan to conduct other studies using a quantitative system analysis to measure the validity of the retrieved information.

This evaluation (Figure 10) focused on user experience. These items are a subset of the MoBiS-Q questionnaire [Voulle, 2008] and we have applied a Likert-type scale to evaluate the validity of each item (where 5 is the highest rating and it means "fully satisfactory" and 1 is the lowest rate meaning "not satisfactory at all"). The users evaluated the use of augmented objects to obtain augmented-reality-based information adapted to their needs. In general, the users gave high ratings to most of items. Specifically, the average agreement was 75.25%, and the rating average was 4.35 out of 5. They gave lower ratings to issues related to the mobile user interface; thus, it could be improved. We have analysed groups of users divided by technological familiarity and applied a one-way ANOVA. We have rejected the hypothesis that the groups were equivalent with respect to technological familiarity; we have obtained significantly high P-values for questions related to the minimization of user memory needs, ease of learning, and simplicity of navigation in the groups divided according to technological experience. In general, we learned that concerns must be addressed to improve usability for every type of user. The ANOVA results also determined the equivalence of the two groups for the functional items (first graph) in the questionnaire. Consequently, the main goals of this proposal have been reached.

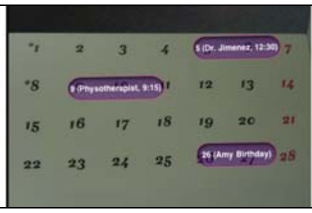
Application	**Pictures**
How to turn the washer on.	 
Semantics	Not applicable
How to prepare meat depending on the current medical situation, for example, based on arterial pressure or glucose level.	 
Semantics	Biometrical signals obtained from MoMo framework [18].
Which medication the user has to take and when is the next doctor's appointment.	 
Semantics (SWRL)	MobileDevice (?m) & User (?u) & owner (?u,?m) & medicine (?md) & swrlb:lessThan ((op:substract-dates (now (?t) & dose (?md, ?u)), doseMargin (?md)) => toShowAR (?md, ?u)

Table 1: Examples of mobile augmented-reality for Ambient Assisted Living

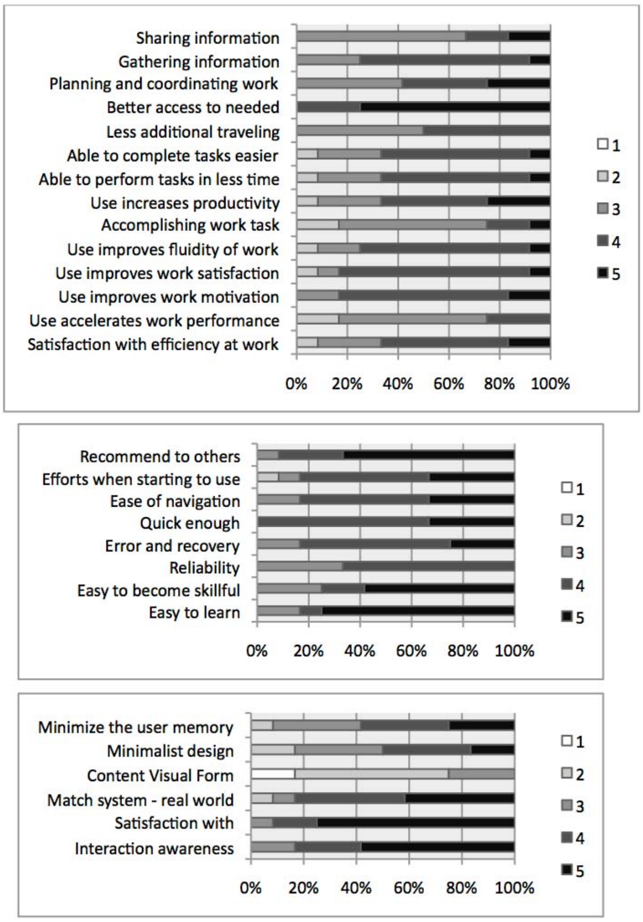


Figure 10: User experience evaluation.

6 Related Work

There have been numerous proposals for augmented reality, which have focused on several scenarios. For example, in mHealth, authors [Bretón-López, 2010] have developed a system to analyze anxiety level by simulating a real phobia-inducing situation and generating an adapted therapy. Feiner and Henderson [Henderson, 2010] have proposed an augmented-reality-based system to train soldiers on mechanical repairs in military environments. There are also several applications to train physicians, for example, in surgery [Lamata, 2010].

However, context-aware augmented reality through mobile devices is still an area that warrants further exploration. Most of the advances in this field use a partial view of the context, typically focused on location and user preferences. A few recent publications explore this topic at a deeper level. For example, the CAMAR system

[Oh, 2008] personalizes displayed content based on a context representation. In contrast with our proposal, however, CAMAR does not follow a generalist and reusable perspective, nor does it include reasoning techniques

7 Conclusions

This proposal describes an infrastructure to support adaptive retrieval information following an augmented-reality perspective. Using an ontological context model by means of Semantic Web principles, information retrieved for users can be personalized to their current situation and needs. This adaptive behaviour exploits the semantic axioms of the OWL language and the expressiveness of a simple language such as SWRL.

Apart from adaptive information, the i-ARA architecture implements a general and reusable mechanism to transform the positioning of relevant information on a mobile user interface, updating it according to user movements based on compass and accelerometer values.

In summary, the main requirements for context-aware augmented reality have been analysed and implemented through a unified and extensible system that explores the use of Semantic Web principles, more specifically, OWL ontologies and adaptive behaviour using SWRL

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